

**A1307-300-IFS-2**

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**INTERFACE SPECIFICATION  
FOR THE  
THREAT SIMULATOR LINKING ACTIVITIES NETWORK**

**CONTRACT NO. F08635-92-C-0050**

**CDRL SEQUENCE NO. (A042)**

Prepared for:

Joint Advanced Distributed Simulation Program Office

Joint Test Force

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## TABLE OF CONTENTS

<b>1. SCOPE.....</b>	<b>1</b>
1.1. Item Description .....	1
1.2. Document Overview .....	1
1.3. Contractors.....	2
<b>2. APPLICABLE DOCUMENTS .....</b>	<b>3</b>
2.1.1. Specifications .....	3
2.1.2. Standards .....	3
2.1.3. Other.....	3
2.1.4. Drawings .....	3
2.1.5. Other Publications.....	3
2.2. Non-Government Documents .....	4
2.2.1. Specifications .....	4
2.2.2. Standards .....	4
2.2.3. Drawings .....	4
2.2.4. Other Publications.....	4
<b>3. INTERFACE REQUIREMENTS .....</b>	<b>4</b>
3.1. Physical.....	5
3.1.1. Operator Interface .....	5
3.1.2. Facility/Entity Interface .....	6
3.1.3. Network Interface.....	6
3.2. Functional .....	6
3.2.1. Operator Interface .....	6
3.2.2. Facility/Entity Interface .....	7
3.2.3. Network Interface.....	7
3.3. Electronic .....	7
3.3.1. Operator Interface .....	7
3.3.2. Facility/Entity Interface .....	7
3.3.3. Network Interface.....	7
3.4. Electrical .....	7

3.5. Hydraulic and Pneumatic .....	7
3.6. Environmental .....	7
3.7. Safety.....	7
<b>4. QUALITY ASSURANCE PROVISIONS .....</b>	<b>8</b>
<b>5. GLOSSARY.....</b>	<b>8</b>
<b>APPENDIX A. TSLA OBJECT CLASS STRUCTURE TABLE.....</b>	<b>10</b>
<b>APPENDIX B. TSLA FOM ATTRIBUTE PARAMETER TABLE .....</b>	<b>11</b>
<b>APPENDIX C. TSLA COMPLEX DATATYPE TABLE.....</b>	<b>Error! Bookmark not defined.</b>
<b>APPENDIX D. TSLA ENUMERATED DATA TYPES .....</b>	<b>28</b>
<b>APPENDIX E. LATENCY COMPENSATION METHOD.....</b>	<b>30</b>
E.1. Performance Requirements .....	30
E.1.1. Latency Range .....	30
E.1.2. Prediction Accuracy .....	30
E.2. Data Update Interval .....	30
E.3. Computation of State Estimates .....	31
<b>APPENDIX F. LAN TO WAN TO LAN DESIGN CONSIDERATIONS.....</b>	<b>32</b>
F.1 Introduction.....	32
F.2. Ethernet.....	32
F.2.1 Segment Size.....	33
F.2.2 Timeout, Retransmission and Backoff.....	34
F.2.3 Network Load .....	34
F.3. Leased Line.....	36
F.3.1 Attribute Size.....	36
F.4. Delay .....	38
F.5. Conclusion .....	40
F.5 1. Data Bandwidth .....	40
F.5 2. Transmission Delay.....	40

**LIST OF FIGURES**

Figure 1. TSLA Network Interface Architecture.....	2
Figure 2. Capabilities and Interfaces for the CDRSS. ....	5
Figure 3. TCP/IP Minimum Data Overhead .....	34
Figure 4. T-1 Usable Bandwidth vs Application Data Size .....	36

28 August 1997

## 1. SCOPE

### 1.1. ITEM DESCRIPTION

Linking of existing test facilities is seen as a method for enhancing the realism and thoroughness of Test and Evaluation (T&E) for Electronic Warfare (EW) assets. These individual test facilities, for the most part, already exist. The linking is to be accomplished through the communication services available from the commercial long-haul carriers which also already exist. The network interactions are to be carried out according to the interface specifications defined by the Defense Modeling and Simulation Office in the High Level Architecture Interface Specification.

The *system* is actually a collection of assets networked together to form an integrated piece of test equipment. The assets include the existing facilities which support EW T&E, the commercial long-haul leased communication networks which support transport of test and control data, and the Run-Time Infrastructure (RTI) developed to provide HLA services.

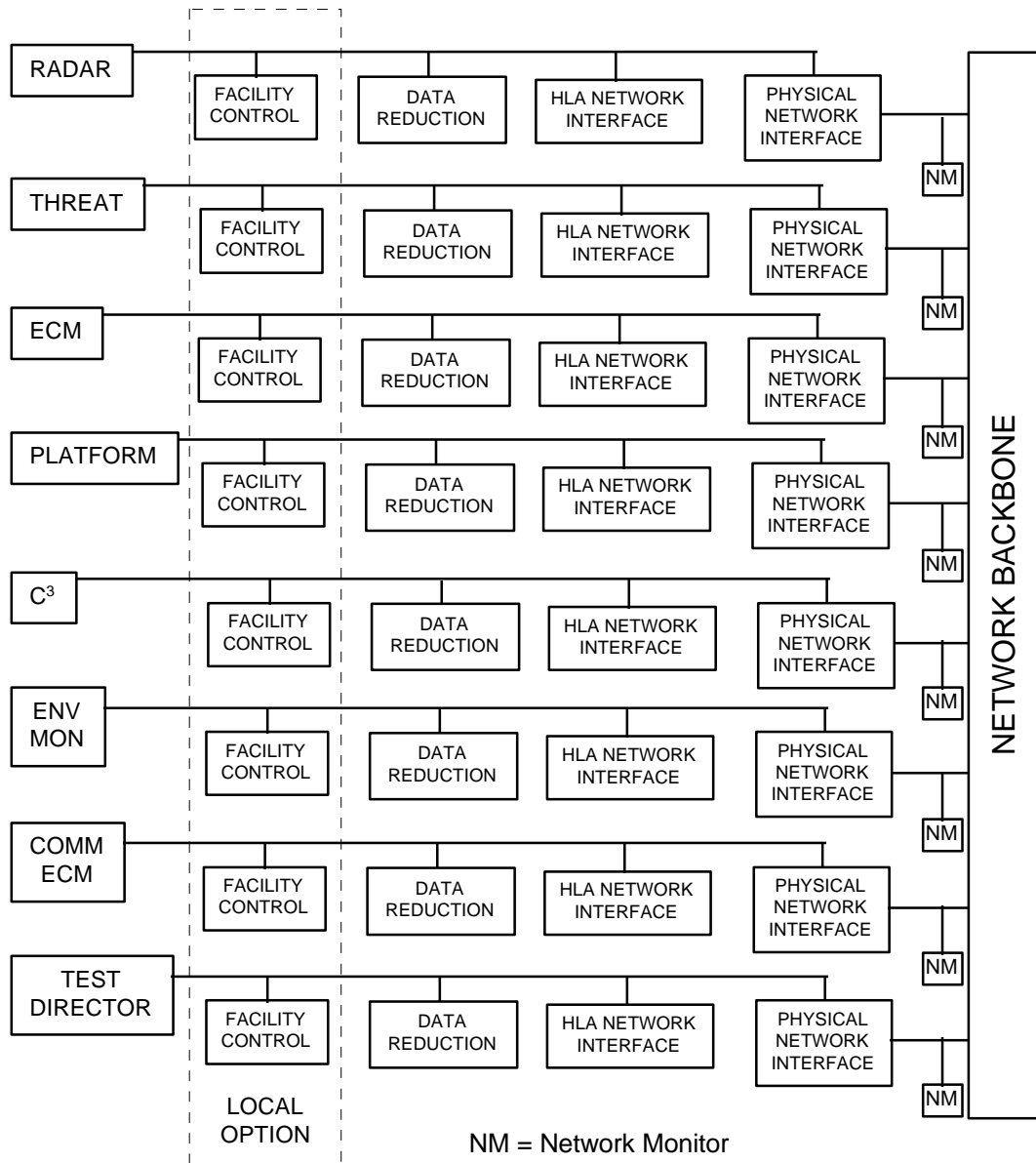
The overall TSLA network is comprised of several components. Many of these components already exist or are in various stages of development. In particular, there are several test facilities which offer existing capabilities for several of the required entity classes. An overall network architecture is shown in Figure 1 to standardize the development of the TSLA Network.

Each of the entities/facilities shall employ common capabilities to interface to the network. A Facility Control service, where it is currently employed by an entity/entity facility, may remain in use at the facility which supports the entity(ies). The HLA Network Interface is the software layer which converts the interface provided by the entity/entity Facility Control to that required by HLA. The Physical Network Interface is the low level driver interface needed to support the connection to the physical transport layer used in the TSLA Network.

### 1.2. DOCUMENT OVERVIEW

Requirements for the communication infrastructure and the RTI are incorporated here by reference. The coupling of these assets to the remaining system assets is addressed in this specification. Enumerated requirements appear in several sections of this document in addition to the section text. These enumerated requirements are to be considered in addition to the requirements defined in the text.

28 August 1997



**Figure 1. TSLA Network Interface Architecture.**

This Interface Specification defines the requirements for external interfaces for the Control Display and Reduction Software Segment (CDRSS). This software is required to interface test facilities to the communication network in an HLA-compliant manner.

### 1.3. CONTRACTORS

TBD

**28 August 1997**

## **2. APPLICABLE DOCUMENTS**

### **2.1.1. SPECIFICATIONS**

1. MIL-T-31000 - General specifications for Technical Data Package Lists
2. High Level Architecture Rules, version 1.0, dated 15 Aug 1996
3. High Level Architecture Interface Specification, version 1.1, dated 12 Feb 1997
4. High Level Architecture Object Model Template, version 1.1, dated 12 Feb 1997
5. Network Requirements Specification for Threat Simulator Linking Activities in support of EW Testing, 22 April 1997.
6. System Specification for the TSLA Network, 27 June 1997, or current version.
7. Software Requirements Specification for the Control, Display, and Reduction Software Segment 27 June 1997, or current version.

### **2.1.2. STANDARDS**

1. MIL-STD 1521B, Notice 1 - Technical Reviews and Audits for Systems, Equipments, and Computer Software
2. MIL-STD-129K, Notice 1 - Marking for Shipment and Storage
3. MIL-STD 481B - Configuration control - engineering Changes (short form), Deviations and Waivers
4. MIL-STD-483A - Configuration Management Practices for Systems, Equipment, Munitions, and Computer Programs
5. MIL-STD-794E, Notice 1 - Parts and Equipment, Procedures for Packaging of,
6. MIL-STD-882B, Notice 1 - System Safety Program Requirements
7. MIL-STD-100E - Engineering Drawing Practices
8. MIL-STD-461C, Notice 2 - Electromagnetic Emission and Susceptibility Requirements for Control of Electromagnetic Interference
9. MIL-STD-462, Notice 6 - Electromagnetic Interference Characteristics, Measurements of
10. World Geographic Society Standard (1984) MIL-STD-2401 World Geodetic System, WGS-84.
11. MIL-STD-1472D, Human Engineering Design Criteria For Military Systems, Equipment and Facilities
12. MIL-H-46855B, Human engineering Requirements for Military Systems, Equipment and Facilities

### **2.1.3. OTHER**

1. AF-MAN- 99-112: Air Force Electronic Warfare T&E Process Manual, 27 March 1995.
2. Feasibility Study Report, "Joint Advanced Distributed Simulation," Prepared by ODDR&E (T&E), Final Report, February 1995.
3. DoD 5220.22M - Industrial Security Manual for Safeguarding Classified Information

### **2.1.4. DRAWINGS**

None

### **2.1.5. OTHER PUBLICATIONS**

None

**28 August 1997**

## **2.2. NON-GOVERNMENT DOCUMENTS**

The following documents of the exact issue shown form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

### **2.2.1. SPECIFICATIONS**

None

### **2.2.2. STANDARDS**

1. Information technology--Local and metropolitan area networks--Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications, ANSI/IEEE Std 802.3, 1996 Edition
2. Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 2: Logical link control, ANSI/IEEE Std 802.2, 1994 Edition.
3. Synchronization Interface Standards for Digital Networks (ANSI T1.101-1994)
4. Digital Hierarchy - Electrical Interfaces (ANSI T1.102-1993)
5. Exchange-Interexchange Carrier Interfaces-Individual Channel Signaling Protocols (ANSI T1.104-1991)
6. Digital Hierarchy - Formats Specifications (ANSI T1.107-1995)
7. IEEE-STD-1278.1 - Standards for distributed Interactive Simulation (DIS) -- Application Protocols, 1993.
8. Current InterNIC standards on TCP/IP protocol and document in current Request For Comments (RFC) Documents. At the time of this specification, the current RFC was 1780.

### **2.2.3. DRAWINGS**

None

### **2.2.4. OTHER PUBLICATIONS**

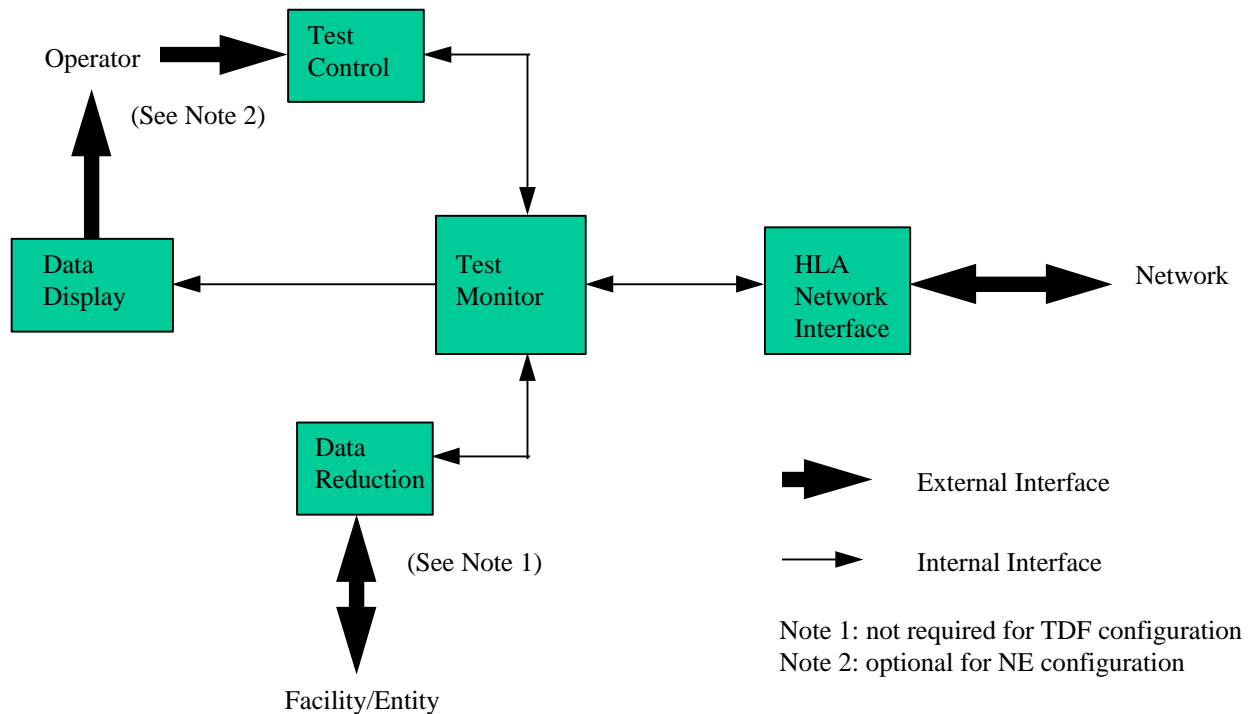
None

Copies of specifications, standards, drawings and publications required by suppliers in connection with the specified procurement functions should be obtained from the contracting agency or as directed by the contracting officer.

## **3. INTERFACE REQUIREMENTS**

The capabilities defined for the CDRSS are indicated in Figure 2. The sections which follow, define the physical, functional, facility, electronic, and electrical interface requirements for all of the external interfaces of the CDRSS.

28 August 1997



**Figure 2. Capabilities and Interfaces for the CDRSS.**

### 3.1. PHYSICAL

#### 3.1.1. OPERATOR INTERFACE

The CDRSS shall provide an operator interface which shall be configurable to function as required at any of the installations for any entity type. Control inputs, and data display choices shall be provided to support operation at any of the entity/facility types defined in the TSLA Network System Specification. The entire collection of control and display capabilities defined in the Software Requirements Specification for the CDRSS shall be supported by this interface.

The control and display for the operator interface shall be physically located in accordance with accepted ergonomic standards as defined in MIL-STD-1472D.

The display for the operator interface shall be a raster color CRT with at least 19" diagonal viewing area. The display resolution shall be at least 1024x768 pixels, with a color depth of at least 256. The dot pitch shall be no larger than 0.28mm. The minimum frame rate shall be 72Hz. Frame rates equal to the fundamental or any harmonics of the prime power frequency are unacceptable.

The control input shall be designed to minimize steps required for executing any command required during the real-time execution of the test. A graduated interface design shall be implemented. The

graduation in capability shall permit simplified operation for novice users, at the expense of efficiency. For more advanced users, the interface shall provide less obvious, but more efficient methods for control and display.

### **3.1.2. FACILITY/ENTITY INTERFACE**

The facility interface to the CDRSS must be configurable to support local installation requirements. Fundamentally, this interface must be adaptable to permit access to all data required to generate the structured attributes and interactions defined for an entity/facility See Appendix B. As such, this interface is not standardized by this specification, but is left to local option for implementation.

### **3.1.3. NETWORK INTERFACE**

Interface to the network shall be in accordance with ANSI/IEEE Std 802.2 (Data layer) and ANSI/IEEE Std 802.3 (physical layer), or any other transport protocols supported by the Run-Time Infrastructure.<sup>1</sup>

## **3.2. FUNCTIONAL**

### **3.2.1. OPERATOR INTERFACE**

The following requirements are extracted from the TSLA System Specification, Section 3.7.9.2.3.

Req. 1. The Operator Interface shall have the ability to display a scenario map while the test is proceeding.

Req. 2. The Operator Interface shall have the ability to display the test status while the test is proceeding.

Req. 3. The Operator Interface shall have the ability to display a SUT display while the test is proceeding.

Req. 4. The Operator Interface shall have the ability to display SUT performance measures according the requirements arising from federation development.

Req. 5. The Operator Interface shall have the ability to display a filter center plot board while the test is proceeding.

Req. 6. The Operator Interface shall have the ability to display the network status while the test is proceeding.

Req. 7. The Operator Interface shall have the capability to communicate directly to facility personnel using voice communications.

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<sup>1</sup> It is assumed that the physical interface from an entity or a facility is representable as a local area network. This specification defines the physical and data standards to be met by the LAN. For long haul communications, the LAN communications process will need to be converted to the time-division multiplexed process employed by the long-haul providers. The bridge between the LAN and the long-haul provider is considered to be a part of the long-haul communications equipment.

28 August 1997

### **3.2.2. FACILITY/ENTITY INTERFACE**

All data required to support the generation of attributes and interactions required for an entity type shall be acquired from that entity by the data reduction interface. Any external data required by the entity shall be provided through the data reduction interface, as obtained from information received in structured attributes and interactions from other entities through the network interface. Attribute structures and data element definitions as defined in Appendices B and C shall be supported.

### **3.2.3. NETWORK INTERFACE**

The network interface shall be in compliance with the API library for the current version of the Run Time Infrastructure as defined in the HLA Interface Specification.

## **3.3. ELECTRONIC**

### **3.3.1. OPERATOR INTERFACE**

Not Applicable

### **3.3.2. FACILITY/ENTITY INTERFACE**

The electronic interface of the facility to the TSLA network shall be determined locally by the entity/facility personnel.

### **3.3.3. NETWORK INTERFACE**

The electronic interface to the TSLA network shall be a bridge to convert the collision-based transport protocol of the LAN to the TDM format used on the long-haul links. Issues to consider when selecting equipment to support the bridging, routing, and multiplexing are discussed in Appendix F to this specification.

## **3.4. ELECTRICAL**

Not Applicable

## **3.5. HYDRAULIC AND PNEUMATIC**

Not applicable

## **3.6. ENVIRONMENTAL**

Not Applicable

## **3.7. SAFETY**

Not Applicable

#### 4. QUALITY ASSURANCE PROVISIONS

This item shall be tested for conformance to the quality assurance provisions of the system specification using the test methods defined in that specification.

#### 5. GLOSSARY

AAA	Anti-Aircraft Artillery
AIR	Airborne Interceptor Radar
BIT	Built-In Test
bps	bits per second
C3	Command, Control, and Communication
C4I	Command, Control, Communications, Computers, and Intelligence
CD	Collision Detect
CD-R	Compact Disk Recordable
COTS	Commercial Off-the-Shelf
CSMA	Carrier Sense Multiple Access bus
DDS	56 kbps Digital Data Service
DIS	Standard for Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Organization
DOD	Department of Defense
DS-1	Digital Signaling 1 (the signaling method for T-1 lines, 1.544 Mbps)
ECM	Electronic Countermeasure
ESF	Extended Super-frame Formatting
EW	Electronic Warfare
EWR	Early Warning Radar
FIFO	first-in first-out
FOM	Federation Object Model
FTP	File Transfer Protocol
GCI	Ground Control Intercept Radar
GPS	Global Positioning System
GUI	Graphical User Interface
HFR	Height Finder Radar
HITL	Hardware (Human) In The Loop
HLA	High-Level Architecture
IADS	Integrated Air Defense System
IEEE	Institute for Electronic and Electrical Engineers
IP	Internet Protocol
JADS	Joint Advanced Distributed Simulation
kbps	1E3 bits per second
LLB	Leased Line Bridge
Mbps	1E6 bits per second
ms	1E-3 seconds
MWR	Missile Warning Receiver
MWX	Missile Warning Radar
ns	1E-9 seconds
OMT	Object Model Template
PDU	Protocol Data Unit
pps	packets per second
QA	Quality Assurance

**A1307-300-IFS-2****28 August 1997**

RCS	Radar Cross Section
RF	Radio Frequency
RID	RTI Initialization Data
RTI	Run-Time Infrastructure
RWR	Radar Warning Receiver
SARH	Semi-Active Radar Homing
SOM	Simulation Object Model
SUT	System Under Test
T&E	Test and Evaluation
TAR	Target Acquisition Radar
TCP	Transmission Control Protocol
TDM	Time-Division Multiplexed
TDMA	Time-Division Multiple Access
TEL	Transporter Erector Launcher
TELAR	Transporter Erector Launcher and Radar
TES	Target Engagement System
TSLA	Threat Simulator Linking Activity
TSPI	Time Space Position Information
TTR	Target Tracking Radar
UDP	User Datagram Protocol
WGS	World Geographic Society

28 August 1997

**APPENDIX A. TSLA OBJECT CLASS STRUCTURE TABLE**

Object Class Structure Table		
Entity	Radar Base	EW Radar
		HF Radar
		TA Radar
		TT Radar
		AI Radar
		MW Radar
	Threat Base	Command Guided Missile
		Active Missile
		Artillery
		SemiActive Missile
	Warning Base	Radar Warning Receiver
	ECM Base	Jammer
		Towed Jammer
		Chaff Dispenser
	C3	
	Stand Alone Monitor	
	Comm ECM	
	Platform	
Facility Controller		
Test Director		

**APPENDIX B.      TSLA FOM ATTRIBUTE PARAMETER TABLE**

**A1307-300-IFS-2**

**28 August 1997**

Attribute/Parameter Table										
Attribute/Parameter Table										
Object/Interaction	Attribute/Parameter	Datatype	Card	Units	Res	Accuracy	Accuracy Condition	Update Type	Update Condition	Bytes
Entity.Radar_Base.EW_Radar	EWRadardPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	53
Entity.Radar_Base.HF_Radar	HFRadardPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	53
Entity.Radar_Base.TA_Radar	TARadardPDUStruct	Complex Data Type						conditional	0.05 sec update interval passed	53
Entity.Radar_Base.TT_Radar	TTRadardPDUStruct	Complex Data Type						conditional	0.025 sec update interval passed 0.01 sec for Guidance	151
Entity.Radar_Base.AI_Radar	AIRadardPDUStruct	Complex Data Type						conditional	0.025 sec update interval passed 0.01 sec for Guidance	135
Entity.Radar_Base.MW_Radar	MWRadardPDUStruct	Complex Data Type						conditional	0.025 sec update interval passed	37
Entity.ThreatBase.CommandGuidedMissile	CommandGuidedMissilePDUStruct	Complex Data Type						conditional	0.025 sec update interval passed	71
Entity.ThreatBase.ActiveMissile	ActiveMissilePDUStruct	Complex Data Type						conditional	0.025 sec update interval passed	71
Entity.ThreatBase.Artillery	ArtilleryPDUStruct	Complex Data Type						conditional	0.025 sec update interval passed	71
Entity.ThreatBase.SemiActiveMissile	SemiActiveMissilePDUStruct	Complex Data Type						conditional	0.025 sec update interval passed	71
TestDirector	TestDirectorPDUStruct	Complex Data Type						conditional	1.0 sec update interval passed	46
FacilityController	FacilityControllerPDUStruct	Complex Data Type						conditional	1.0 sec update interval passed	46
Entity.WarningBase.RadarWarningReceiver	RadarWarningReceiverPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	17
Entity.ECMBase.ChaffDispenser	ChaffDispenserPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	90
Entity.ECMBase.Jammer	JammerPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	93
Entity.ECMBase.TowedJammer	TowedJammerPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	105
Entity.C3	C3PDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	86
Entity.StandAloneEnvironmentMonitor	StandAloneEnvironmentMonitorPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	15
Entity.CommunicationECM	CommunicationECMPDUStruct	Complex Data Type						conditional	0.1 sec update interval passed	89
Entity.Platform	PlatformPDUStruct	Complex Data Type						conditional	0.025 sec update	104

A1307-300-IFS-2

28 August 1997

Attribute/Parameter Table										
Attribute/Parameter Table										
Object/Interaction	Attribute/Parameter	Datatype	Card	Units	Res	Accuracy	Accuracy Condition	Update Type	Update Condition	Bytes
									interval passed	

## **APPENDIX C.      TSLA COMPLEX DATATYPE TABLE**

See TSLA Network Requirements Specification 28 February 1997, Appendix A for a description of the information in each of these complex data types.

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
EWRadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	scan_period	long		ms	1		
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	begin_pulse	bool					
	checksum	unsigned long					
HFRadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_command	Complex Type					
	nod_period	long		ms	1		
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	begin_pulse	bool					
	checksum	unsigned long					
TARadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	boresight_azimuth	int		deg	0.1		
	boresight_elevation	int		deg	0.1		
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	checksum	unsigned long					
TTRadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	boresight_azimuth	int		deg	0.1		
	boresight_elevation	int		deg	0.1		
	track_error_azimuth	int		deg	0.1		
	track_error_elevation	int		deg	0.1		
	track_error_range	long		m	0.1		
	jammer_to_signal_ratio	int		db	0.1		
	signal_to_clutter_ratio	int		db	0.1		
	op_command	Complex Type					
	op_response	Complex Type					
	engagement_result	enum	EngagementResultEnum				
	miss_distance_x	long		m	0.1		
	miss_distance_y	long		m	0.1		
	miss_distance_z	long		m	0.1		
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	track_status	bool					
	checksum	unsigned long					
AIRadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	platform_serial_number	int					
	boresight_azimuth	int		deg	0.1		
	boresight_elevation	int		deg	0.1		
	track_error_azimuth	int		deg	0.1		
	track_error_elevation	int		deg	0.1		
	track_error_range	long		m	0.1		
	jammer_to_signal_ratio	int		db	0.1		
	signal_to_clutter_ratio	int		db	0.1		
	op_command	Complex Type					
	op_response	Complex Type					
	engagement_result	enum	EngagementResultEnum				

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	miss_distance_x	long		m	0.1		
	miss_distance_y	long		m	0.1		
	miss_distance_z	long		m	0.1		
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	track_status	bool					
	checksum	unsigned long					
MWRadarPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	local_target_tag	int					
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	platform_serial_number	int					
	boresight_azimuth	int		deg	0.1		
	boresight_elevation	int		deg	0.1		
	azimuth_valid	bool					
	elevation_valid	bool					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	range_valid	bool					
	doppler_valid	bool					
	injection_verified	bool					
	emission_verified	bool					
	checksum	unsigned long					
CommandGuidedMissilePDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	radar_serial_number	int					
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_response	Complex Type					
	armed	bool					
	launch_status	bool					
	target_lock	bool					
	checksum	unsigned long					
ActiveMissilePDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	radar_serial_number	int					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_response	Complex Type					
	armed	bool					
	launch_status	bool					
	target_lock	bool					
	checksum	unsigned long					
ArtilleryPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	radar_serial_number	int					
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_response	Complex Type					
	armed	bool					
	launch_status	bool					
	target_lock	bool					
	checksum	unsigned long					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
SemiActivePDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	radar_serial_number	int					
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_response	Complex Type					
	armed	bool					
	launch_status	bool					
	target_lock	bool					
	checksum	unsigned long					
TestDirectorPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	director_command	Complex Type					
	director_response	Complex Type					
	checksum	unsigned long					
FacilityControllerPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	director_command	Complex Type					
	director_response	Complex Type					
	checksum	unsigned long					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
RadarWarningPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	platform_serial_number	int					
	warning	bool					
	emission_verified	bool					
	checksum	unsigned long					
ChaffDispenserPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	platform_serial_number	int					
	op_command	Complex Type					
	op_response	Complex Type					
	checksum	unsigned long					
JammerPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	power_percent	int		%	0.1		
	platform_serial_number	int					
	op_command	Complex Type					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	op_response	Complex Type					
	injection_verified	bool					
	emission_verified	bool					
	checksum	unsigned long					
TowedJammerPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	mode_serial_number	int					
	power_percent	int		%	0.1		
	platform_serial_number	int					
	position_offset_x	long		m	0.1		
	position_offset_y	long		m	0.1		
	position_offset_z	long		m	0.1		
	op_command	Complex Type					
	op_response	Complex Type					
	injection_verified	bool					
	emission_verified	bool					
	checksum	unsigned long					
C3PDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	op_command	Complex Type					
	op_response	Complex Type					
	checksum	unsigned long					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
StandAloneEnvironmentMonitorPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	verified	bool					
	checksum	unsigned long					
CommunicationECMPDUStruct	SerialNumber	int					
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	azimuth	int		deg	0.1		
	elevation	int		deg	0.1		
	range	long		m	0.1		
	doppler	long		Hz	1		
	op_command	Complex Type					
	op_response	Complex Type					
	engagement_result_enum	enum					
	azimuth_valid	bool					
	elevation_valid	bool					
	range_valid	bool					
	doppler_valid	bool					
	armed	bool					
	launch_status	bool					
	target_lock	bool					
	checksum	unsigned long					
PlatformPDUStruct	SerialNumber	int					

**A1307-300-IFS-2**

**28 August 1997**

Complex Datatype Table							
Complex Datatype	Field	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
	time	unsigned long		ms	1		
	entity_status	enum	EntityStatusEnum				
	communication_status	enum	CommunicationStatusEnum				
	position_x	long		m	0.1		
	position_y	long		m	0.1		
	position_z	long		m	0.1		
	orientation_phi	int		deg	0.1		
	orientation_theta	int		deg	0.1		
	orientation_psi	int		deg	0.1		
	op_command	Complex Type					
	op_response	Complex Type					
	checksum	unsigned long					
OpCommandStruct	op_code	enum	OpCodeEnum				
	data	char[34]					
	checksum	unsigned long					
OpResponseStruct	op_code	enum	OpCodeEnum				
	data	char[34]					
	checksum	unsigned long					
DirCommandStruct	op_code	enum	OpCodeEnum				
	data	char[16]					
	checksum	unsigned long					
DirResponseStruct	op_code	enum	OpCodeEnum				
	data	char[16]					
	checksum	unsigned long					

28 August 1997

**APPENDIX D. TSLA ENUMERATED DATA TYPES**

Enumerated Datatype Table		
Identifier	Enumerator	Representation
CategoryEnum	CATEGORY_UNKNOWN	0
CommunicationStatusEnum	COMM_OKAY COMM_LATE COMM_FAULT	0 1 2
CountryEnum	COUNTRY_UNKNOWN	0
DirOpCodeEnum	DIR_NOP	0
DomainEnum	DOMAIN_UNKNOWN	0
ECMTechniqueEnum	ECM_UNKNOWN ECM_NOISE ECM_FALSE_TARGET	0 1 2
EngagementResultEnum	ENGAGE_UNKNOWN ENGAGE_PENDING ENGAGE_ENGAGING ENGAGE_KILL ENGAGE_NO_KILL	0 1 2 3 4
EngagementStatusEnum	ENGAGE_NOT_ENGAGED ENGAGE_ENGAGE	0 1
EntityKindEnum	KIND_UNKNOWN	0
EntityStatusEnum	ENTITY_ON ENTITY_OFF ENTITY_STANDBY ENTITY_FAIL	0 1 2 3
ExtraEnum	EXTRA_UNKNOWN	0
OpCodeEnum	OP_NOP OP_ARM OP_ASSIGN OP_DETONATE OP_GUIDE OP_HANDOFF OP_INTERCEPT OP_LAUNCH OP_SWITCH OP_SENLOCKSTATUS	0 1 2 3 4 5 6 7 8 9

28 August 1997

Enumerated Datatype Table		
Identifier	Enumerator	Representation
	OP_SENDTARGETZONE	10
	OP_CHAFF_DISPENSE	11
RadarTypeEnum	RADAR_UNKNOWN	0
	RADAR_EW	1
	RADAR_HF	2
	RADAR_TAR	3
	RADAR_TTR	4
	RADAR_AIR	5
	RADAR_MWR	6
RadarOperationEnum	RADAROP_UNKNOWN	0
	RADAROP_SCAN	1
	RADAROP_TRACK	2
	RADAROP_HEIGHTFIND	3
SubCategoryEnum	SUBCATEGORY_UNKNOWN	0
SpecificEnum	SPECIFIC_UNKNOWN	0

## **APPENDIX E. LATENCY COMPENSATION METHOD**

### **E.1. PERFORMANCE REQUIREMENTS**

The distributed nature of the test network, and the processing time of the RTI will insert some amount of latency in the delivery of data to the end user. For the purposes of this specification, latency is defined as the difference in time between when data are measured by the data generator and when the data reaches the data consumer. The data generator shall time tag the data to correspond to the time that the measurement was made. The data consumer shall record the time the data was provided. The time difference is the latency.

The approach to latency compensation is to estimate the *state* of the dynamic system (e.g. the platform position and velocity in a 6-state model, or its position, velocity and acceleration in a 9-state model) and then use these estimates to predict its future position. If the state estimates are accurate when transmitted, then predictions based on a kinematic extrapolation will remain accurate until the highest derivative of the target state that is used in the predictor changes from the value in the transmitted estimate.

#### **E.1.1. LATENCY RANGE**

The expected range of values for latency in the test network is difficult to determine reliably. Also, it is recognized that latency compensation can only be performed for those data sources where the highest derivatives in the underlying system model remain constant during the interval of compensation. (The state variables include things like *position* which need not remain constant (of course). What must remain constant is either the system model, or perhaps the highest derivative modeled). For flight encounters of interest, it would be unreasonable to expect that the highest order derivative would remain constant for longer than 0.5 seconds. Hence, on this basis, the maximum range of compensation for latency shall be 0.5 seconds.

#### **E.1.2. PREDICTION ACCURACY**

The accuracy of prediction following latency compensation shall be less than 0.5 meters for range and less than 0.1 milliradian for azimuth and elevation.

### **E.2. DATA UPDATE INTERVAL**

The required update interval is dictated by a) the actual data transmitted from generator to consumer, and b) the minimum expected interval of time over which the highest derivatives of the state variables can be expected to remain constant. For the platforms of interest to EW testing (i.e., tactical aircraft and missiles) the maximum interval over which these state variables can be expected to remain constant is 25ms. This shall be the maximum update interval for state estimates.

### **E.3. COMPUTATION OF STATE ESTIMATES**

The TSLA network shall include, at each data generator, a filter capable of producing estimates of the current (3-space) position of the platform, and the first time derivatives of these parameters. The updates

of these estimates shall be provided at a 40Hz rate. The TSLA network shall require that a predictor algorithm be implemented at each data consumer (where latency compensation is required) which will operate with the state estimates to produce predictions with accuracy as specified in Section E.1. If there is a requirement for raw (unfiltered data) these data values shall be transmitted within the same data structure as that for the filtered state estimates.

The rationale for this specification is provided in the paragraphs below.

There are two parts to the latency compensation process. The first part is a filtering process which produces accurate estimates of the system state variables. The second part is an extrapolation process which uses the state estimates to form a predicted value of position based on the state estimates. The prediction computation is relative to the time of the state estimates. The time for the prediction is the current time.

There are three possible implementations of the filter-predictor process. In the first two methods, the filter is located at the data generator, while predictor is resident at the data consumer. There are two cases here because, with the filter, it is possible to provide updates of the state estimates at a rate different from the sample interval provided by the measurement sensor. The data generator can monitor test the results of predictions which would be made by the current state estimates, and only provide updates to the state estimates when these predictions exceeded some error tolerance. Or, in the second approach, the data generator could simply provide a state update each time there was a new measurement. The first approach provides the opportunity to reduce the amount of data traffic. But, it requires the data generator to test for the condition when the prediction error becomes too large. Also, this approach has the limitation that the state is updated only after it is determined that the current state estimate will produce excessive prediction error. Hence, there is an inherent latency built in to this approach.

The third approach places both the filter and the predictor at the data consumer node. This approach is appealing whenever there is a need for the raw sensor data to be transmitted over the network (For example if it is required for use in test data reduction.) In this situation, both the filter and the predictor are implemented at the data consumer node. Here, the drawback is that each data consumer must now support the computational burden of the filter.

## **APPENDIX F. LAN TO WAN TO LAN DESIGN CONSIDERATIONS**

### **F.1. INTRODUCTION**

The data passed between entities should be formatted so that the maximum effective use of the available communication resource is achieved. If the selection of a communication infrastructure is a free design parameter, the analysis can evaluate differences between transmission options such as point-to-point, packet-switched, broadcast, reflective memory, etc. The analysis can also evaluate the data structures and the associated transmission overhead (e.g., framing bits, address bits, data identification, etc.) so that the minimum data granularity may be established. Depending on the selected transmission option, attribute update rate, attribute association (e.g., certain attributes that are almost always generated, transmitted, and consumed as a group), and attribute dispersion (e.g., different subsets of the total attribute set that are required by different consumers) the desired granularity of the data in a packet may range between fine grain (e.g., byte data or several bytes per packet), and coarse grain (e.g., hundred(s) of bytes per packet). If the communication infrastructure is not a free design parameter, the nature of the infrastructure must be understood, and the data granularity must be appropriately chosen to achieve good performance.

### **F.2. ETHERNET**

In the case of TSLA, the assumed local-area communication infrastructure is Ethernet, the assumed protocol suite is TCP/IP, and the application interface is RTI. (In general, the following discussion also applies to the UDP/IP protocol suite except that the overhead would be slightly less, and the packet rate would be slightly greater due to UDP's unreliable transport.) The data packet begins with a structured attribute in the application layer. As the data packet is formatted for the network, the size grows as the packet moves from the application through successive layers consisting of RTI, Host, Internet, and Physical. (The layers cited correspond to the DoD architecture which only roughly corresponds to the OSI layered model.) Each layer adds specific information to allow successful routing of the data from the producer to the consumer.

The data overhead associated with the Host, Internet, and Physical layers are well known. The data overhead associated with the RTI layer is not currently available. In an application, a data structure is defined with a byte size that depends on the data underlying the structure. The data structure is passed to the RTI layer using an API function call (e.g., `updateAttributeValues`). The RTI layer potentially adds control information to the data structure, generating an RTI datagram. The RTI datagram is passed to the Host layer where transport-level data are added, generating a TCP (or UDP) datagram. The TCP datagram is passed to the Internet layer where routing data are added, generating an IP datagram. Finally the IP datagram is passed to the Physical layer where framing bits, check sum bits, and physical routing data are added, resulting in an Ethernet packet. At the receiving end, the layers are traversed in the opposite direction until the data structure is available to the consuming process.

During transmission, the movement of data through the layers adds data overhead. The amount of overhead added at each layer is shown in Figure 3. For an Ethernet packet, the minimum amount of overhead added to the data is 66 bytes. Thus, a data structure composed of a single byte can use at most

28 August 1997

use 1/67 of the available bandwidth. The gross bandwidth and available bandwidth are different. The available bandwidth is smaller due to a required interframe gap of 9.6  $\mu$ s. The interframe gap is equivalent to 12 bytes of overhead on a 10 Mbps Ethernet.

The achievable transfer rate in bits-per-second from application-layer to application-layer is very difficult to generally define. The TCP/IP literature is very vague concerning bit-per-second data throughput. This is probably due to the many technical considerations that influence the throughput. The segment size, timeout constraints, retransmission, backoff, and network load all influence both the instantaneous, and the average data rates.

### F.2.1 SEGMENT SIZE

Segment size refers to the byte length of the maximum IP datagram that will traverse from producer to consumer as a single, intact datagram. If the datagram length is larger than this size, network equipment may split the datagram into multiple datagrams. This operation impacts network congestion and retransmission.

Determining the optimum segment size is difficult for several reasons. The primary reason for the difficulty is that the TCP/IP standard does not include a mechanism for doing so. Secondary reasons include,

1. a potentially dynamic connection path (different datagrams may pass through different equipment sets resulting in different fragmentation size requirements), and
2. the optimum size depends on data contained in lower levels (e.g., IP header options).

If the selected segment size is too small, overhead bits become a larger percentage of the packet, potentially wasting bandwidth. If the selected segment size is too large, fragmentation and repackaging by less capable segments into multiple packets will add both time delay and data overhead. An IP packet size of 576 bytes is recommended because this is the maximum packet size that should not be fragmented by network equipment.

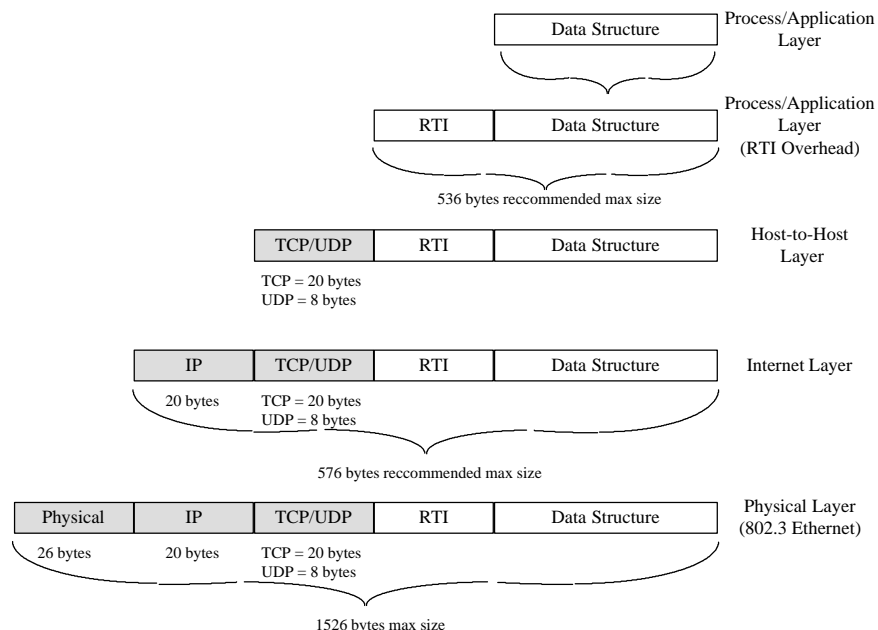


Figure 3. TCP/IP Minimum Data Overhead

## F.2.2 TIMEOUT, RETRANSMISSION AND BACKOFF

Timeout values are determined using an adaptive retransmission algorithm that monitors the performance of each connection to generate reasonable timeout values. The connection performance is measured in terms of the round trip delay between a transmission and acknowledgment cycle. As the network becomes more heavily loaded, round trip delays and delay variances increase. The adaptation algorithm's parameters are tuned for a particular range of delay variance values so that in a heavily loaded network unnecessary timeout-retransmit conditions are more likely to occur. This wastes bandwidth because in many cases, the data indeed reached the destination but the round trip time exceeded the timeout value, forcing a retransmission.

Timeout and retransmit would overwhelm the network if procedures were not in place to limit retries on heavily loaded segments. These procedures increase the timeout delay for each unsuccessful, successive transfer attempt. Karn's Algorithm is generally referenced as the method for generating the next timeout value. Once network congestion has cleared, and round-trip delays are back to normal, a slow-start procedure is used to help avoid an immediate reoccurrence of congestion as all senders attempt to return to full speed operation. The TCP/IP standard references both *slow start* and *multiplicative decrease* as strategies that should be implemented to avoid congestion problems.

## F.2.3 NETWORK LOAD

The interactions between packet size, access algorithms, and network loading make it very difficult to analytically determine the percentage of utilization where the performance of a network will deteriorate. There are several experimental studies that may be used to formulate general guidelines. These guidelines may be used as an aid in evaluating the suitability of transmission media, in determining an estimate of peak transfer rate, and in specifying the granularity of data structures.

One reference to a Berkeley study indicated that "TCP ... can deliver 8 Mbps of sustained throughput between two workstations on a 10 Mbps Ethernet.[1, pg. 201]" To examine this claim and its implications, assume that the fundamental Ethernet rate is not measured in bps but rather in packets-per-second (pps). Further assume that the Berkeley study used the maximum possible Ethernet packet size of 1526 bytes, corresponding to a data size of  $1460 \times 8 = 11680$  bits per packet. The resulting calculations produce a sustained data transfer rate of 685 pps on a 10 Mbps physical Ethernet. The actual number of packets on the network could be in fact be twice this number due to the presence of TCP acknowledgment packets.

A second referenced study done by IBM related the mean transfer delay to the total information throughput in Mbps for 802.3 (Carrier Sense Multiple Access bus with Collision Detection (CSMA/CD)), and 802.5 (Token Passing Ring) access control methods[2, pp. 52-59]. It is assumed in this discussion that 802.3 (CSMA/CD) would be used by the TSLA local area networks. For a 10 Mbps Ethernet, the transfer delays were observed to increase asymptotically as throughput increased. The asymptotes occurred at total transfer rates of approximately 3.8, 5.5, and 7.0 Mbps for packet sizes of 1000, 2000, and 4000 bits, respectively. From this study, the total network packet-per-second rate appears to be on the order of 2800

pps, however, packet delivery delays at high packet rates were on the order of several milliseconds. This delay size is an indication that numerous collisions were occurring. Moving away from asymptotic behavior results in a sustained, low-delay, point-to-point data packet rate in the 500 to 1000 pps range. There is a trade-off between packet size and bits-per-second bandwidth. Larger packet sizes appear to have a bit-per-second advantage beyond the advantage predicted by overhead calculations.

Moving to an operating region away from asymptotic behavior yields data rates of approximately 1.0, 2.5, and 3.5 Mbps for packet sizes of 1000, 2000, and 4000 bits, respectively. The 4000 bit number relates well to the recommended packet size of 576 bytes, and the 3.5 Mbps rate relates well with the 32% rate derived from the Berkeley study. The IBM study also shows that measuring the network capacity in packets per second instead of bits per second is reasonably accurate except for extremely light network loading and/or very small packet sizes.

From these two studies, a very rough rule-of-thumb relationship between packet size and a low-delay data rate may be stated.

Packet Size	Sustained bps Rate	Approximate Attribute Size
1000 bits	1 Mbps	500 bits
2000 bits	2 Mbps	1500 bits
4000 bits	4 Mbps	3500 bits

### F.3. LEASED LINE

Now that the performance of a 10 Mbps Ethernet with the potential for collision and retransmission is better understood, the leased line interface (e.g., 56k, T-1, T-3, etc.) between multiple Ethernet segments may be examined. The assumption is that the connection between a 10 Mbps Ethernet segment and the leased line will have at least the packet filtering capability of an Ethernet bridge. This assumption means that IP packets transferred to the leased line will have destination addresses that require leased line transmission. In other words, the connection will not act as a repeater. The interface will be generically referred to as an LLB (leased-line bridge) in the discussion that follows.

The LLB acts as a first-in-first-out (FIFO) filter between the 10 Mbps Ethernet and the leased line. Once a packet has been transferred to the LLB, the packet is queued and buffered for an orderly transmission to the LLB at the other end of the point-to-point leased line. It is important to note that no collisions are possible with a point-to-point connection and that the bandwidth utilization for the entire packet can approach the total bandwidth specification of the leased line. The amount of data in the queue and the load on the receive-end local area network will affect the total latency from producer to consumer.

The LLB also acts as a physical format converter. The Ethernet's physical signaling is changed to/from leased line physical signaling by the LLB. Because the leased line uses time-division multiplexing (TDM) there is no physical concept of Ethernet packets. Unlike Ethernet, the signaling bits always use the same amount of overhead. Leased lines use the term *frame* in place of the term *packet*. Since no collisions are possible, the frame data overhead always represents a constant percentage of the total specified bandwidth. Two standard data rates for leased lines are 56 kbps (DDS) and 1.536 Mbps (T-1). The presence of signaling bits on the T-1 line accounts for the difference between the data rate, and the more commonly quoted DS-1 signaling rate (i.e., 1.544 Mbps).

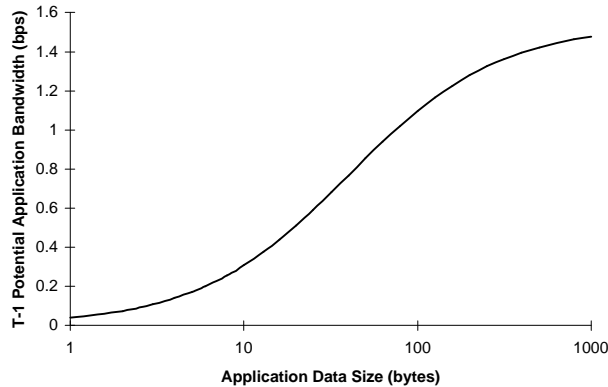
28 August 1997

### F.3.1 ATTRIBUTE SIZE

As long as the buffer in the LLB always has data, a rough estimate for the potential application data rate on a leased line can be obtained from,

$$\text{Application bps} = (\text{Leased Line bps}) * \left( \frac{\text{Data Size in bytes}}{40 + \text{Data Size in bytes}} \right)$$

Figure 4 shows the application bandwidth versus data size for a T-1 line. A data size greater than 40 bytes results in a potential application bit rate of greater than 700 kbps. The utilization is described as potential because actually achieving a sustained application rate depends on the condition that the LLB is never starved for data.



**Figure 4. T-1 Usable Bandwidth vs Application Data Size**

To get an estimate of the minimum acceptable packet size, two LLB operational cases must be considered. In the first case the LLB maps a single TCP/IP packet into a single extended super-frame (ESF). In this case the best data size is identical to the data size of the ESF (i.e., 576 bytes) and the maximum sustained packet rate is the ESF rate of the leased line (i.e., 333 pps). In the second case, the LLB allows TCP/IP packets to span multiple ESFs. In this case, the information from the 10 Mbps Ethernet bandwidth discussion may be used to derive a packet-size estimate. In the 10 Mbps Ethernet discussion it was conjectured that a rate of approximately 685 pps represented the peak rate. Further, it was shown that each Ethernet packet contains 26 bytes of physical layer data, 40 bytes of TCP/IP layer data, and some variable number of data bytes. The physical-layer data are removed in going from Ethernet to the leased line so that an estimate of the minimum data size to achieve maximum leased line utilization, in bytes, may be obtained from,

$$\text{Attribute Size in bytes} \cong \frac{1}{8} \left( \frac{\text{Leased Line bps}}{685 \text{ pps}} \right) - 40.$$

The above expression is only approximate because the overhead associated with the separation of TCP/IP packets in the leased line data stream has not been considered. In addition, the 685 pps rate is at best only an average value. The expression will provide a 'ball park' estimate.

For a T-1 line, the approximate non-starving data size is 240 bytes. For data sizes smaller than the non-starving size, some of the TDM data slots will be empty, resulting in un-utilized bandwidth. For example, a data size of 100 bytes, times 685 pps results in an average application data bandwidth of 548 kbps, even though the potential bandwidth is approximately 1 Mbps. In this case, the 10 Mbps Ethernet does not provide data at a rate high enough to completely take advantage of the T-1's bandwidth.

For data sizes larger than the non-starving size, the potential for dropped packets and/or long delays exist. The combination of a 685 pps rate and a packet size larger than the non-starving size has the potential to fill the LLB buffer if the pps rate is a sustained rate. This will result in buffer overflow and dropped packets. Even if the higher pps rate only occurs for a short period of time, movement of the buffered data onto the leased line will introduce a maximum delay proportional to the length of the buffer.

#### F.4. DELAY

The potential disadvantage of making the data size large are delays associated with the exchange of packets between equipment on the network. The data in an entire structured attribute must be collected before a packet may be transferred from the computer onto the publisher's Ethernet. The entire packet must be received by the LLB before the data may be formatted and transferred to the leased line. At the other end of the line, some number of frames must be received before a packet may be transferred to the subscriber's Ethernet. Finally at the subscriber, the entire packet must be received before the data may be consumed. The approximate delay versus packet length characteristics can be approximated by focusing on the delays associated with each step.

The total delay may be written,

$$\begin{aligned} \text{Delay} = & \text{Delay}_{LAN,1} + \text{Delay}_{publisher} \\ & + \text{Delay}_{FIFO,1} + \text{Delay}_{distance} + \text{Delay}_{frame} + \text{Delay}_{FIFO,2} + \text{Delay}_{LAN,2}, \\ & + \text{Delay}_{subscriber} \end{aligned}$$

where each of the individual delay components are described below.

The first delay element is the time associated with obtaining the use of the local area network ( $\text{Delay}_{LAN,1}$ ). On a network where collisions are not possible, this time would probably be constant (and possibly zero).

Once the publisher has gained access to the network, the entire packet must be delivered to the LLB before the packet can be processed. Thus, the delay between publisher and LLB ( $\text{Delay}_{publisher}$ ) is assumed to equal the number of bits times the individual bit time. This delay may be approximated by,

$$\text{Delay}_{publisher} = (66 + \text{Data Size in Bytes}) \left( \frac{8}{9.896 \text{ Mbps}} \right),$$

Once the packet has been received by the LLB, there is a delay between the time the packet is completely received and the time a frame may be transmitted. This delay ( $\text{Delay}_{FIFO,1}$ ) depends on the amount of data in the FIFO buffer, the processing speed of the LLB, and the position in the current ESF.

Once the ESF datagram has progressed to the transceiver of the LLB, the leased-line delay must be considered. The leased-line delay depends on many variables, however, distance ( $Delay_{distance}$ ) and framing ( $Delay_{frame}$ ) are the two primary delay components.

The distance component consists of delays associated with the propagation velocity in the transmission medium and the number of amplifiers in the transmission circuit. The commercial long-haul carriers can provide this delay information. Propagation delays are on the order of 8 ms per 1000 miles. Circuit-equipment delays depend on the circuit configuration and range from 8 ms (two amps, two fiber terminations) to 32 ms (six amplifiers plus ten fiber terminations).

The delays associated with framing depend on the operation of the LLB and the size of the datagram. Assuming the use of ESF formatting, the cases to consider are,

1. full T1 bridging and datagram  $\leq 576$  bytes,
2. full T1 bridging and datagram  $> 576$  bytes, and
3. fractional T1 bridging.

In the first case, each TCP/IP datagram will fit entirely within an ESF so that there is a one-to-one mapping between Ethernet packets and T1 frames. In this case, the framing delay is the number of data bits in one frame times the individual bit time given by,

$$Delay_{frame,case1} = \left( \frac{8 * 576}{1.536 \text{ Mbps}} \right).$$

In the second case, the LLB will fracture the datagram into two or more TCP/IP datagrams and two or more frames. This impacts the frame delay, however, the generation of multiple TCP/IP datagrams will also increase the total delay between the receiving LLB and the consumer. The framing delay can be calculated from,

$$Delay_{frame,case2} = \left\lceil \frac{Attribute \text{ Size}}{576 - 40} \right\rceil \left( \frac{8 * 576}{1.536 \text{ Mbps}} \right),$$

where  $\lceil \cdot \rceil$  represents rounding up to the next larger integer. Operating under this scenario should be avoided because fracturing one datagram into multiple TCP/IP datagrams increases the amount of network traffic and causes retransmission problems. The additional delays imposed by datagram fracturing will therefore not be considered.

In the third case, the LLB can potentially spread the TCP/IP datagram across several frames regardless of the datagram size. The datagram is not fractured because multiple TCP/IP datagrams are not created. The minimum and maximum delays can be calculated as,

$$Delay_{frame,case3,min} = \left\lceil \frac{Attribute \text{ Size in bytes}}{Fractional \text{ Channels} * 24} \right\rceil \left( \frac{8 * 576}{1.536 \text{ Mbps}} \right), \text{ and}$$

$$Delay_{frame,case3,max} = \left\lceil \left\lceil \frac{Attribute \text{ Size in bytes}}{Fractional \text{ Channels} * 24} \right\rceil + 1 \right\rceil \left( \frac{8 * 576}{1.536 \text{ Mbps}} \right),$$

respectively. The probability that the minimum delay will be achieved for a particular datagram may be approximated by,

$$P_{\min} \cong 1 - \left[ \frac{\text{Attribute Size in bytes}}{\text{Fractional Channels} * 24} \right].$$

After the datagram reaches the transceiver in the second LLB, there is a delay ( $Delay_{FIFO,2}$ ) between the time the data are received and the time the data are ready to be transmitted on the consumer's local area network. There is also a delay associated with obtaining the use of the consumer's local area network ( $Delay_{LAN,2}$ ). On a network where collisions are not possible, the LAN delay time would be constant (and possibly zero).

Finally, once the second LLB has gained access to the network, the delay between LLB and subscriber ( $Delay_{subscriber}$ ) is assumed to equal the number of bits times the individual bit time. This delay may be approximated by,

$$Delay_{subscriber} = (66 + \text{Data Size in Bytes}) \left( \frac{8}{9.896 \text{ Mbps}} \right).$$

The individual delay elements on a datagram-to-datagram basis are summarized below.

$Delay_{LAN,1}$	<i>Variable, depends on the instantaneous loading of the publisher's local area network</i>
$Delay_{publisher}$	<i>Constant, depends on the publisher's local area network's bandwidth capability</i>
$Delay_{FIFO,1}$	<i>Variable, depends on the instantaneous loading and the capability of the publisher's LLB</i>
$Delay_{distance}$	<i>Constant, depends on commercial carrier, distance, medium, and circuit elements</i>
$Delay_{frame}$	<i>Potentially Variable, depends on the LLB mode and datagram size</i>
$Delay_{FIFO,2}$	<i>Variable, depends on the instantaneous loading and the capability of the subscriber's LLB</i>
$Delay_{LAN,2}$	<i>Variable, depends on the instantaneous loading of the subscriber's local area network</i>
$Delay_{subscriber}$	<i>Constant, depends on the subscriber's local area network's bandwidth capability</i>

## F.5. CONCLUSION

### F.5 1. DATA BANDWIDTH

In the case of bandwidth utilization, the best data size depends on the bandwidth of the leased line connecting the Ethernet segments. Larger data structures, 100 bytes or larger, appear to make better use of the bandwidth when compared to smaller data structures, less than 40 bytes. If possible, multiple time samples might be packaged into 576 byte IP packets to minimize the chance of fragmentation into multiple packets by the LLB, and to minimize the effect of overhead. The disadvantage of packaging multiple samples is the time skew that will exist between the samples. This skew will be less than sending multiple packets in most cases.

## **F.5 2. TRANSMISSION DELAY**

In the case of total data transmission delay, the signal propagation and long-haul equipment delays appear to be much larger than the Ethernet-T-1 access delays. The significance of the access delays become important for regional facilities where the propagation time is small and the number of amplifier hops is also small. The variability caused by fractional-T-1 equipment also becomes more significant in these cases. The T-1 access delays depend strongly on the operation of the LLB (framing, packet construction, etc.) and the amount of fractional-T-1 bandwidth allocated to the data traffic. The strategy for minimizing delays relies on the use of smaller data sizes so that the probability of a single TCP/IP packet occupying more than one LLB frame is reduced. With full-T-1 LLBs, a IP packet size of 576 bytes or smaller will achieve this objective. With fractional-T-1 LLBs, a small packet size will reduce the probability of spanning multiple LLB frames, however, the delay variability will increase.

To reduce the delay associated with collision avoidance, the number of computers that logically share a single subnet should be kept to a minimum. Bridges (or the equivalent) should be used to filter network traffic and isolate congested subnets. The use of broadcast messages should be kept to a minimum, and judicious use of multi-cast groups should be made. Finally, the use of UDP instead of TCP will reduce the possibility of collision since acknowledgment and retransmission packets are not required. Consideration of these techniques should allow the maximum throughput to be achieved.

Maximizing the use of network bandwidth requires large packet sizes. Minimizing the total delay requires small packet sizes. In the middle ground there is an optimal value that depends on network loading, fractional bandwidth, framing strategy, and equipment sophistication. It is recommended that a testing program be used to determine the delay associated with the RTI and LAN-to-WAN connectivity. Packet size and update rates would be used to provide a basis for selecting a particular structured-attribute size.

- [1] D. E. Comer, Internetworking with TCP/IP, Second Ed., Vol. I, Prentice Hall, NJ, 1991.
- [2] M. A. Miller, Internetworking, A Guide to Network Communications, LAN to LAN; LAN to WAN, M&T Publishing, CA, 1991.